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EVALUATING 1 AND 2D DIMENSIONAL MODELS FOR FLOODPLAIN INUNDATION MAPPING

by

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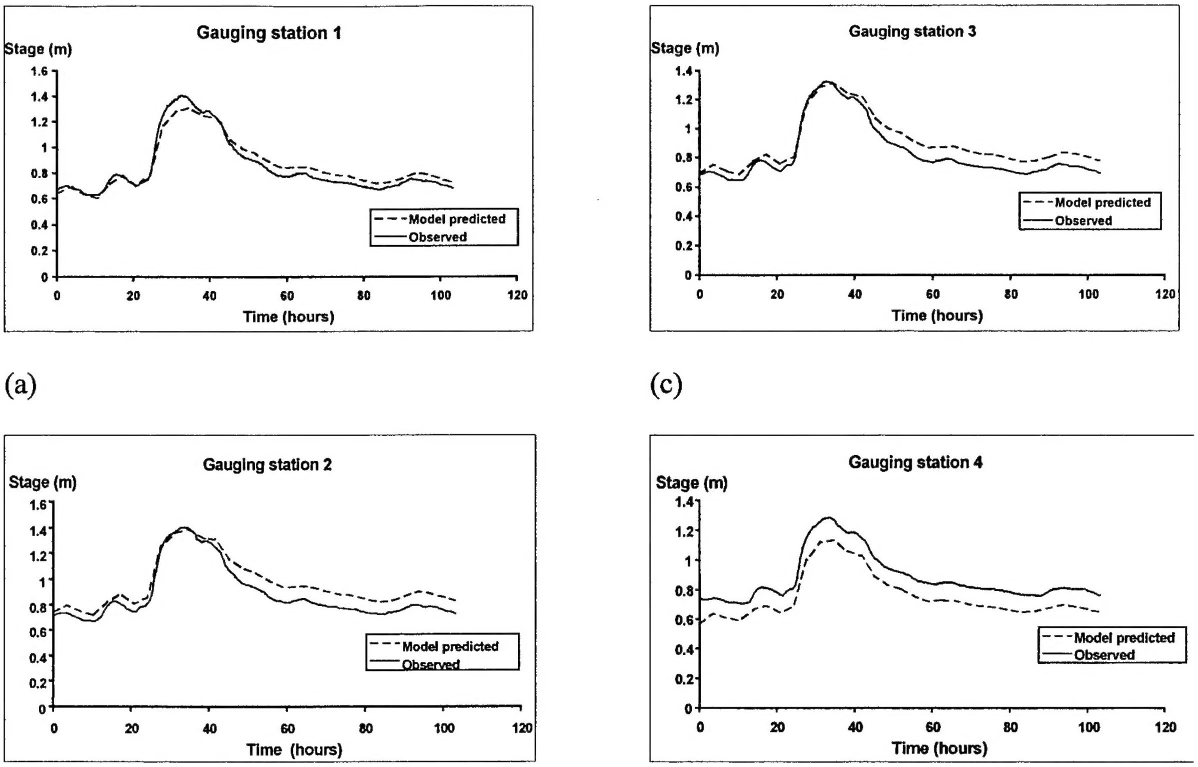
Recent work has illustrated the potential of two dimensional finite element codes for modelling flow in meandering compound channels (Samuels, 1985, Gee *et al.*, 1990; Bates *et al.*, 1992; Feldhaus *et al.*, 1992; Anderson and Bates, 1994). Such models have been shown to offer a number of advantages over alternative one (Cunge *et al.*, 1980; Fread, 1985) and two (Zeike and Urban, 1981) dimensional finite difference schemes due to their ability to represent complex topography with a minimum number of computational nodes and the potential accuracy of the finite element method (Huyakorn and Pinder, 1983).

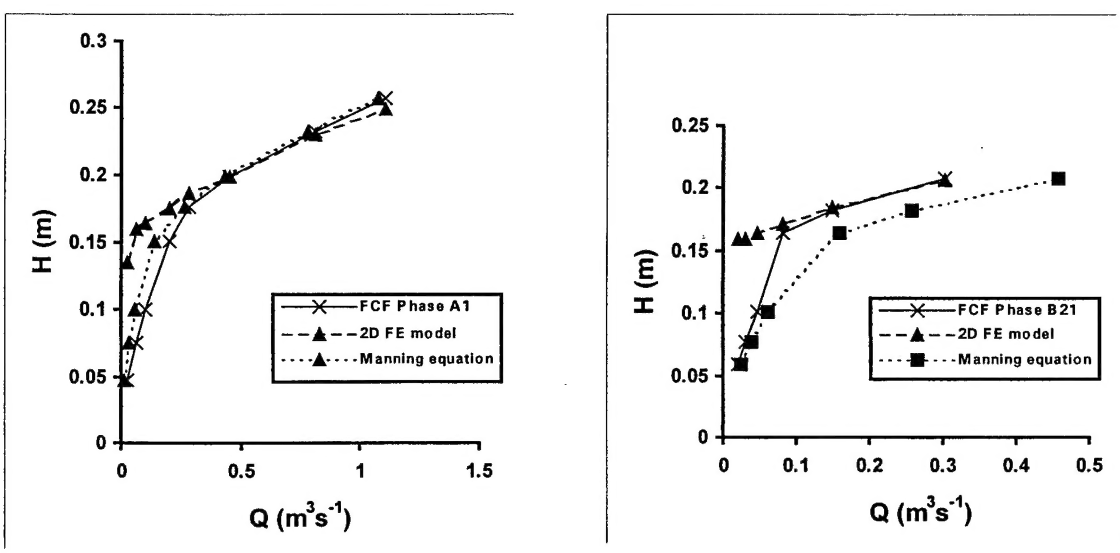
Whilst the potential utility of this class of scheme for river flow applications is clear, insufficient model validation remains a major constraint on the development of practical engineering tools. In particular, current studies largely compare model predictions to real observations on the basis of bulk flows (discharges) at the reach downstream boundary (see for example Gee *et al.*, 1990). This result is typically achieved through calibration of the model friction parameters to replicate this downstream hydrograph and, as a consequence, the calibration and validation phases are not independent. Given the number of degrees of freedom present in such calibration, whereby separate friction parameters can be assigned at each computational node and at each time step, a reasonable correspondence between observed reach outflow data and a calibrated flood routing model (of any dimensionality or spatial resolution) is relatively easy to accomplish. Moreover, there is a strong element of equifinality in this calibration procedure as many different parameterization sets may produce equally acceptable fits to a given set of observed data. The quality of this type of evidence as proof that the model is a robust predictive tool is therefore questionable, and in using such data it has proved impossible to disaggregate error due to model parameterization, structural or discretization errors, data errors or flaws in the calibration procedure itself.

Similar validation problems exist with more traditional, one dimensional approaches to flood routing, however the recent move towards two dimensional simulations renders the situation much more acute. Flood routing requires a limited number of prediction products from numerical models. However, for an increasing number of applications, in particular sediment transport and pollution studies, the spatially distributed velocity and water depth fields predicted by two dimensional models are of direct relevance. From the above discussion it is clear that much further validation evidence is required if any confidence is to be placed in the distributed flow field predictions which two dimensional models also generate. A need therefore exists to conduct model validation against high quality data which is independent of any friction calibration procedure undertaken. Such data has recently become available through a number of developments in large scale physical modelling (Sellin and Willetts, 1996) and high resolution field data capture (Naish and Sellin, 1995) which now afford the unique possibility of meeting this research need. Accordingly, we have compared a finite element solution of the Shallow Water equations to highly detailed field data from the River Blackwater in the UK (Figure 1) and to data from the EPSRC large scale Flood Channel Facility (FCF) physical model (Figure 2).

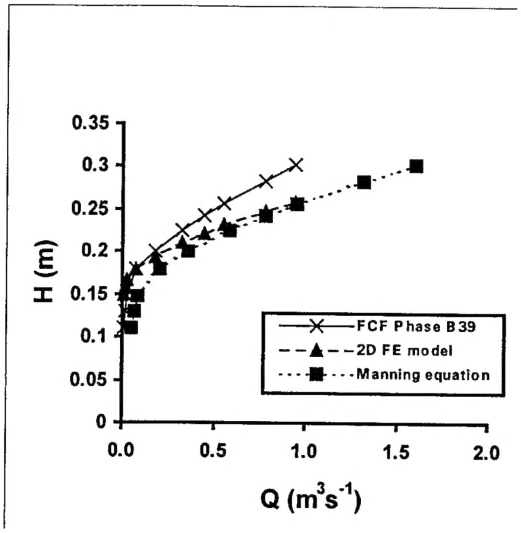


(b) (d)

Figure 1a-d: Comparison of the four observed River Blackwater stage hydrographs available at locations internal to the model computational domain to predictions from a two dimensional finite element model. Note bankful stage is at 0.75 m at each gauging station



(a) (b)



(c)

Figure 2a-c: Comparison of observed stage-discharge rating curves for the three Flood Channel Facility configurations with predictions from the TELEMAC-2D two dimensional finite element model and the Manning equation.

The simulation results described above clearly show that for flood flows in compound channel flow problems simulated at this mesh resolution a two dimensional finite element model with simple turbulence closure is able to accurately predict hydraulic measures such as discharge, stage and inundation extent at internal cross sections. This demonstrates that even with a relatively crude spatial and dimensional discretisation of the lateral velocity gradient in the near channel region the TELEMAC-2D model is able to represent the momentum transfer between main-channel and floodplain flows sufficiently well to replicate typical physical model and field data. This momentum transfer process has been shown to be critical to the development of flood flows in compound channels (Ervine and Baird, 1992) and it has been suggested that its complexity invalidates models which employ a one dimensional representation for out-of-bank conditions (Knight and Shiono, 1996). Effectively, a two dimensional depth averaged model is the simplest scheme that can explicitly represent this process and this study has demonstrated that such a description captures many of its essential attributes. Moreover, the model seems able to represent the additional energy losses which occur due to channel meandering (see for example Sellin and Willetts, 1996). These largely comprise the vigorous mixing of channel and floodplain water across meander loops. Here channel water spills onto the floodplain from the downstream apex of meander bends before flowing across the meander loop and rejoining the main channel flow at the next meander. This is a complex process and may be at least as important as main-channel/floodplain momentum exchange. By comparison the single channel method as applied cannot take into account these energy losses in meandering channels and natural geometries without an empirical correction. In the case of the 110° channel (FCF Phase B39) this failure leads to an under-prediction of stage by the single channel method of up to 20%. This is not surprising given the nature of the single channel method (Myers, 1987) whereby the energy losses are represented solely by a lumped coefficient. As the published roughness coefficient for the FCF is solely a description of the surface

roughness and does not include any additional energy loss mechanisms it is clear that meandering channel energy are highly significant during flood flow conditions.

The two dimensional finite element model does however fail to adequately replicate in-bank flows, although it does appear to correctly simulate the onset of flooding (see for example data point 4 on Figure 2b). This is perhaps unsurprising as the mesh discretization was originally designed to simulate inundation in response to large out-of-bank flood events. However, it is instructive to consider the precise reasons for this inability. While the River Blackwater simulations indicate the scope of the problem, the uncertainties involved in model construction mean that it is impossible to determine whether topographic error, poor optimisation of the boundary friction calibration, flow measurement error or the model assumptions themselves are at fault. The Flood Channel Facility simulations allow all but the latter to be eliminated as explanations as topography, friction and flow can be rigorously controlled for. Clearly, some aspect of the two dimensional model structure is not appropriate for the representation of in-bank flow when that channel is set within a wider floodplain belt. This is unusual as we have already demonstrated that the model is capable of simulating the much more complex out-of-bank case. Indeed, standard hydraulic practice for in-channel flows makes use of a one-dimensional flow field assumption (Knight and Shiono, 1996). It therefore seems unlikely that the model process representation (dimensionality, turbulence closure, friction) is at fault. A better explanation would therefore appear to be the presence of very steep elements representing the channel banks which become partially dry at less than bankful flow. These do not appear to be well represented by the Shallow Water equations, which typically only apply to regions with topographic gradients of less than 10%. Additionally these elements may cause problems with the TELEMAC-2D wetting and drying algorithm which was designed solely for shallow gradient elements on floodplains and tidal flats. Clearly further work is needed to confirm this view and test competing hypotheses regarding the poor performance for in-channel flows.

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